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SOIL COMPACTION INVESTIGATION REPORT 10

MAR. 1968

TECHNICAL MEMORANDUM NO. 3-271

SOIL COMPACTION INVESTIGATION

Report 10

EVALUATION OF VIBRATORY ROLLERS ON THREE TYPES OF SOILS

by

J. W. Hall

March 1968

Sponsored by

U. S. Air Force

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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36

REPORTS OF THIS SERIES ENTITLED "SOIL COMPACTION INVESTIGATION"
TECHNICAL MEMORANDUM NO. 3-271

Report No.	Title	Date
1	Compaction Studies on Clayey Sands	Apr 1949
2	Compaction Studies on Silty Clay	July 1949
3	Compaction Studies on Sand Subgrades	Oct 1949
4	Subgrade Compaction Studies	Feb 1950
5	Miscellaneous Laboratory Tests	June 1950
6	Effect of Size of Feet on Sheepsfoot Roller	June 1954
7	Effect on Soil Compaction of Tire Pressure and Number of Coverages of Rubber-Tired Rollers and Foot-Contact Pressure of Sheepsfoot Rollers	June 1956
8	Effect of Lift Thickness and Tire Pressure	Oct 1957
9	Compaction of a Graded Crushed-Aggregate Base Course	Sept 1963
10	Evaluation of Vibratory Rollers on Three Types of Soils	Mar 1968

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SOIL COMPACTION INVESTIGATION: REPORT 10. EVALUATION OF VIBRATORY ROLLERS ON THREE TYPES OF SOILS

Jim W. Hall

Army Engineer Waterways Experiment Station
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ARMY-MRC VICKSBURG, MISS

FOREWORD

This investigation is part of the continuing Air Force program sponsored through Military Construction, Office, Chief of Engineers, for developing construction methods and techniques for flexible pavements.

The study described herein was accomplished by personnel of the Soils Division, U. S. Army Engineer Waterways Experiment Station, during the period May through June 1962. Engineers actively engaged in the collection and analysis of data were Messrs. C. D. Burns, A. H. Joseph, and J. W. Hall. The overall study was under the general supervision of Messrs. W. J. Turnbull, A. A. Maxwell, and R. G. Ahlvin.

Director of the Waterways Experiment Station during the conduct of this study was COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter
tons	907.185	kilograms

SUMMARY

This study was conducted for the purpose of determining the ability of vibratory rollers to compact soils. For comparative purposes, a 50-ton rubber-tired roller was used which is a required compaction device in present Corps of Engineers Guide Specifications.

Three vibratory rollers were selected for study based on their operating frequency which encompassed the range over which present vibratory rollers operate. Results of this study show that light vibratory rollers can obtain satisfactory densities if lift thicknesses are restricted. To evaluate the vibratory rollers, each was used to compact three soil types (a lean clay, a crushed limestone, and a clean sand).

Results indicate that a heavy, low-frequency vibratory roller will compact to greater depths than a light, high-frequency roller; however, the light, high-frequency roller will compact soil satisfactorily for a few inches below the surface.

Soil types have a very definite influence on results obtained with vibratory rollers. The vibratory rollers generally perform better in granular soils; however, the heavy, low-frequency type rollers do a satisfactory job in clay soils.

SOIL COMPACTION INVESTIGATION

EVALUATION OF VIBRATORY ROLLERS ON THREE TYPES OF SOILS

PART I: INTRODUCTION

Background

1. The appearance in the past decade of a large variety of vibratory equipment for the compaction of soils has given rise to the question of whether lightweight vibratory equipment can be substituted for conventional compaction equipment, which generally depends on its deadweight to densify soils. Most equipment manufacturers that build compaction equipment are now producing some type of vibratory machine for compacting soils. A large percentage of the vibratory equipment being produced makes use of the principle of an eccentric weight on a rotating shaft to produce the vibrations. The eccentrically weighted rotating shaft is connected to a drum or a plate that is used to transfer the vibrations to the soil. The manufacturers' rating of these compactors is based on the force generated by the eccentrically weighted rotating shaft. This system of rating the compactors is misleading because it ignores the phase lag between the point of generation at the eccentric and the point of compaction within the soil. This rating system is based on the centrifugal force equation:

$$F = Me\omega^2$$

where

F = force, lb*

M = mass of the eccentric weight, $\frac{\text{weight}}{\text{gravity}} = \frac{\text{lb}}{\text{ft/sec}^2}$

e = distance from center of gravity of eccentric mass to center of rotation, in.

ω = angular velocity of the rotating mass in radians per minute, and is equal to (2π) (rpm)

This equation gives the centrifugal force generated at the center of

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

rotation of the eccentric, but due to damping in the roller system and to the relation of the inertial forces of the roller to the generated forces, it is difficult, if not impossible, to compute the compaction effort received by the soil. Flexibility within the roller, but more particularly in the soil, produces damping which can reduce the generated force to a fraction of its original magnitude.

Purpose and Scope

2. The purpose of this investigation was to determine the effectiveness of vibratory rollers for compacting soils. To accomplish this purpose, three vibratory rollers were obtained for the study. The selection of the vibratory rollers was based primarily on the frequency at which they operated with respect to the frequency range over which most vibratory rollers operate. One each from the low-, medium-, and high-frequency ranges was selected for testing. For comparison purposes, a 50-ton rubber-tired roller was also used. In order that the rollers could be evaluated over a range of conditions, each roller was used to compact three types of soils: a crushed limestone, a fine sand, and a lean clay. For each soil, the moisture content was controlled at three different levels, i.e. at wet of optimum, optimum, and dry of optimum, based on the optimum moisture content as obtained from the modified AASHO (MIL-STD-621, CE55) moisture-density relation. (Hereinafter, MIL-STD-621, CE55 moisture-density relation will be referred to simply as modified AASHO maximum density.) This variation of moisture content produced nine conditions of compaction for each roller operated (i.e. three soil types and three moisture contents for each soil). The density of the soil and the depth to which compaction was being obtained were measured throughout the period of traffic by the rollers.

PART II: FIELD TESTS

Test Area

3. The field tests were conducted under shelter at the Waterways Experiment Station (WES) in order that better control could be maintained over all phases of the testing program. Four 90- by 10-ft test lanes were excavated for use in this compaction study, one lane for each of the vibratory rollers (lanes 1, 2, and 3) and a lane (lane 4) for the 50-ton rubber-tired roller. Each lane was divided into three items, which contained soil with dry of optimum, optimum, and wet of optimum moisture contents, respectively. Plate 1 shows a layout of the test section. The test procedure, which was as far as possible identical for each roller, consisted of the compaction of 1-ft-thick lifts of limestone and lean clay and 4-ft-thick lifts of sand (measurements are of compacted thicknesses). After the completion of tests on a particular soil, the soil was removed from the test trenches and replaced by another soil type and the compaction test was repeated. The lean clay material was mixed to the proper moisture content for each item before it was placed in the test trench. The limestone and sand were placed in the trenches with items separated by cutoff walls before the desired moisture was added and mixed into the materials.

Description of Rollers and Traffic Sequence

4. The physical characteristics of the vibratory rollers and the rubber-tired roller used in this compaction study are tabulated below:

Lane	Roller	Type of Roller	Mobility	Deadweight lb	Drum Dimensions in.	rpm Range	Centrifugal Force Generated at Max rpm, lb
1	A	Vibratory	Towed	7,000	48×60	800-1600	15,000
2	B	Vibratory	Towed	3,150	30×54	3600	11,000
3	C	Vibratory	Self-propelled	7,270	48×84	600-1400	25,000
4	D	Rubber-tired	Towed	100,000	(4 tires, 1800×24 in., 90 psi)		

The sequence of traffic for compacting the soil in place had to be varied due to the difference in width of the rollers. For rollers A and B, two passes were required to make a complete coverage of the 10-ft-wide lane. The two passes overlapped 4 to 6 in. in the center of the lane to ensure complete coverage. Roller C, which is 84 in. wide, was passed over the center of the lane one time for a coverage. Two passes of the rubber-tired roller were required for a coverage. For each test lane, 16 coverages were applied.

Soils

5. The soils used in this compaction study (a crushed limestone, a sand, and a lean clay) were selected in an attempt to cover the range of materials generally used in pavement construction. Laboratory tests on these materials were conducted to determine the gradation and modified AASHO maximum density. Plate 2 is a plot of the gradation of the three soils used in this study. Plate 3 shows the moisture-density relations for the soils.

Tests Conducted

6. Since compaction was accomplished for only one lift thickness, it was not practical to determine the density gradient with depth after each coverage of the roller; however, surface densities were measured after 4, 8, and 16 coverages of each roller, and a complete density-depth relation was established after 16 coverages. The density values obtained at various depths at 16 coverages are shown for each soil type at dry of optimum moisture content, at optimum, and at wet of optimum for each of the rollers used in this study in tables 1, 2, and 3 for the sand, limestone, and lean clay, respectively. It can be noted from these tables that the after-traffic moisture contents for the sand and limestone were quite different from the moisture contents at which the soils were compacted. This is the result of the water draining from the high-porosity soils. There is a problem of maintaining moisture in granular soils during

compaction, and it is not known how these changes in moisture affected the results. During the first stages of compaction of the deep sand test lane with the rubber-tired roller, the roller would bog down and it was necessary to use an additional tractor to pull the roller through the sand. After several passes the rubber-tired roller could negotiate the sand lane without the additional tractor, but compaction did not occur from the surface down as it did in the case of the vibratory rollers. Comparisons will be made later herein between the vibratory rollers and the rubber-tired roller since the densities obtained with the rubber-tired roller are considered representative of its capability.

7. Each vibratory roller was instrumented to measure the frequency of its vibration during the compaction process. Instrumentation was also placed in each item of the soil being compacted to measure the frequency of vibration and the vertical movement of the soil. Velocity-type pickups were installed at the center position in each item at the 1-ft depth in the limestone, the lean clay, and lane 1 of the sand section, and at depths of 1, 2, and 4 ft in the items with optimum moisture contents in lanes 2 and 3 of the sand section. Table 5 summarizes the vertical movement of the soils measured by the ground instrumentation.

8. During the field testing in this study, a motorized automatic-recording nuclear moisture and density device (road logger) was used to check the moisture and density of the surface of the compacted soil behind each roller at 1, 2, 4, and 8 coverages. Portions of the data obtained with this device have been incorporated into this report to supplement the conventional data where needed; however, the primary purpose of the testing with this device was to evaluate the device itself. A report of this phase of the field testing will be published separately.

PART III: TEST RESULTS

Compactor A

Sand test section

9. Compactor A was a towed-type vibratory compactor with a gross weight of 7000 lb. The density-depth data taken after 16 coverages on the sand section are presented for all three moisture contents in table 1 and plate 4. The greatest compaction obtained by compactor A for each of the three moisture conditions was 92.2% of modified AASHO maximum density at the 18- to 24-in. depth in the dry of optimum moisture item, 96.2% of modified AASHO maximum at the 12- to 18-in. depth for the optimum moisture item, and 96.7% of modified AASHO maximum at the 6- to 12-in. depth for the wet of optimum moisture item. At greater depths than those corresponding to these maximum values, density fell off sharply as depth increased. Moisture was a big factor in the amount of densification in the sand section; the highest densities were obtained at the wet of optimum moisture content. It is interesting to note from table 4 and plate 7 that the densities in all three items decreased between 4 and 8 coverages and then increased between 8 and 16 coverages. The densities at 16 coverages were less than 1 pcf higher than those at 4 coverages for the optimum and wet of optimum moisture items, and about 7 pcf lower for the dry of optimum item. Overall, compactor A did the poorest job of any of the vibratory compactors in the sand--the densities obtained with compactor A and the rubber-tired roller were about the same at the surface; however, at the 12- to 18-in. depth compactor A obtained only about 90% of that obtained with the rubber-tired roller.

Limestone test section

10. The 16-coverage depth-density data for compactor A in the limestone section are given in table 2, and shown graphically in plate 5. The highest density obtained in the dry of optimum item was 92.5% of modified AASHO maximum at the 0- to 6-in. depth, the highest density in the optimum moisture was 98.1% of modified AASHO maximum at the 0- to 6-in. depth, and the highest density in the wet of optimum item was 97.9%

of modified AASHO maximum at the 6- to 12-in. depth. The highest density obtained in the limestone section by compactor A was the 98.1% of modified AASHO maximum at the 0- to 6-in. depth for the optimum moisture item, but density in this item fell off with depth to a value of 95.8% at the 6- to 12-in. depth. Density values for the other two moisture conditions were practically constant for the entire depth of the section. The density-versus-coverage data given in table 4 and plate 8 show densities increasing with coverages in all three items. The increase in density between 4 and 16 coverages was 6.9 pcf at dry of optimum moisture and 5.2 pcf for both optimum and wet of optimum moisture conditions. The data used in obtaining plate 8 were the road logger data shown in table 4, and do not exactly agree with the values obtained by the direct sampling method which are also shown in table 4 for 16 coverages. The road logger data were the only data obtained at different coverage levels in the limestone section. Compactor A produced about 102% of the compaction developed by the rubber-tired roller for the full 1-ft depth in the wet of optimum item. Density values produced by compactor A for the other two moisture conditions were about 99.5% of those of the rubber-tired roller at the 0- to 6-in. depth and about 101% of those of the rubber-tired roller at the 6- to 12-in. depth for both optimum and dry of optimum items.

Lean clay test section

11. The 16-coverage density-depth data for the lean clay section are presented in table 3 and plate 6. Compactor A obtained its highest density in the lean clay at the optimum moisture content. The maximum values for each item were 91.3% of modified AASHO maximum at the 0- to 2-in. depth for dry of optimum moisture, 94.1% of modified AASHO maximum at the 0- to 2-in. depth for optimum moisture, and 90.7% of modified AASHO maximum at the 0- to 2-in. depth for wet of optimum moisture. Compaction by compactor A was generally equivalent to that of the rubber-tired roller to a depth of 5 in.; as depth increased below that depth, compactor A densities dropped to a low of about 94% of those of the rubber-tired roller at the 8- to 10-in. depth. Density data were obtained at 4 and 16 coverages only and are given in table 4 and plate 9.

Compactor A densities increased between 4 and 16 coverages by 5.0 pcf at dry of optimum moisture content, 8.4 pcf at optimum moisture, and 3.3 pcf at wet of optimum moisture. The rubber-tired roller showed very little added densification between 4 and 16 coverages.

Compactor B

Sand test section

12. Compactor B was a towed-type vibratory compactor with a gross weight of 3150 lb. The 16-coverage density-depth data presented in table 1 and plate 4 show maximum densities to be 92.1% of modified AASHO maximum at the 6- to 12-in. depth for the dry of optimum moisture item, and 104.0% of modified AASHO maximum at the 6- to 12-in. depth for the wet of optimum moisture item. Plate 4 shows that the density increased with depth to a maximum of about 9 in. and decreased sharply below this depth. The maximum densification at each depth occurred in the wet of optimum moisture item. For the 0- to 12-in. depth, compactor B produced about 96% of the compaction produced by the rubber-tired roller at dry of optimum moisture, about 100% at optimum moisture, and 107% at wet of optimum moisture. Plate 4 shows that for depths greater than 9 in., the compactor B density values were all lower than those of the rubber-tired roller. The density-coverage data presented in plate 7 show a decrease in density for compactor B between 4 and 8 coverages and an increase between 8 and 16 coverages to a maximum value for all three moisture contents.

Limestone test section

13. Maximum density values as given in table 2 for compactor B in the limestone section were 91.6% of modified AASHO maximum at the 0- to 6-in. depth for dry of optimum moisture, 94.7% of modified AASHO maximum at the 0- to 6-in. depth for optimum moisture, and 96.1% of modified AASHO maximum at the 0- to 6-in. depth for wet of optimum moisture. Therefore, the greatest density was obtained at wet of optimum moisture content. The rubber-tired roller produced its maximum density at the optimum moisture content. Plate 5 shows density values for compactor B to be much lower than those of the rubber-tired roller except at the 0- to

6-in. depth in the wet of optimum item where the values are about the same. The road logger density-coverage data presented in table 4 and plate 8 show practically no increase in density between 4 and 16 coverages for all three moisture contents, and a slight decrease in density between 4 and 8 coverages for the dry of optimum and wet of optimum conditions.

Lean clay test section

14. The maximum density obtained in the lean clay section was 91.6% of modified AASHO maximum at the 0- to 2-in. depth for optimum moisture content. Maximum densities in the dry of optimum and wet of optimum moisture items were 86.3 and 90.8% of modified AASHO maximum, respectively, both at the 0- to 2-in. depth. As shown in plate 6, the densities produced by compactor B were much lower than those of the rubber-tired roller for all three moisture contents. Compactor B produced from 95% of the compaction of the rubber-tired roller at dry of optimum moisture content to 100% at wet of optimum at the 0- to 2-in. depth, but only about 87% of the compaction of the rubber-tired roller at the 6- to 8-in. depth for all three moisture contents. The density-coverage data of table 4 and plate 9 show increases between 4 and 16 coverages of 7.4, 8.8, and 3.0 pcf for the dry of optimum, optimum, and wet of optimum moisture contents, respectively. Maximum compaction after 4 coverages occurred at wet of optimum moisture, and maximum compaction after 16 coverages occurred at optimum moisture.

Compactor C

Sand test section

15. Compactor C, a self-propelled vibratory compactor with a gross weight of 5270 lb, achieved the highest densities of the vibratory compactors in the sand. The maximum values obtained were 95.3, 97.2, and 102.5% of modified AASHO maximum (all at a depth of 6 to 12 in.) in the dry of optimum, optimum, and wet of optimum moisture items, respectively. Plate 4 shows that between the 0- and 12-in. depths, compactor C produced densities approximately equivalent to those of the rubber-tired roller at dry of optimum and optimum moisture contents, and as much as 111% of the

compaction of the rubber-tired roller at wet of optimum moisture at this same depth. For depths greater than 9 in., compactor C produced about 95% of the compaction of the rubber-tired roller. The surface density-coverage data were similar to those of the other vibratory compactors with a decrease in density between 4 and 8 coverages and then an increase to a maximum value at 16 coverages. At 8 coverages, the densities of the rubber-tired roller were higher than those of compactor C, but after 16 coverages, compactor C densities were equivalent to those of the rubber-tired roller at optimum moisture content and higher at the other two moisture contents. The rubber-tired roller showed an increase in density at optimum moisture content and a decrease in density at dry of optimum and wet of optimum between 8 and 16 coverages.

Limestone test section

16. Compactor C achieved a maximum density of 95.6% of modified AASHO maximum at a depth of 0 to 6 in. and optimum moisture content, with the highest densities at dry of optimum and wet of optimum being 92.7 and 94.8% of modified AASHO maximum, respectively, both at the 0- to 6-in. depth. Compactor C achieved the following percentages of the compaction of the rubber-tired roller: 99% in the dry of optimum moisture item (average of values for all depths), 96.3% at the 0- to 6-in. depth and 97.0% at the 6- to 12-in. depth for the optimum moisture item, and 96.1% at the 0- to 6-in. depth and 89.8% at the 6- to 12-in. depth for the wet of optimum item. At the dry of optimum and wet of optimum moisture contents, compactor C densities showed an increase of about 3 pcf between 4 and 16 coverages. At optimum moisture, there was a decrease in density between 4 and 8 coverages and then an increase to 16 coverages with the increase between 4 and 16 coverages being 6.4 pcf.

Lean clay test section

17. Compactor C achieved a maximum density of 91.7% of modified AASHO maximum at a depth of 0 to 2 in. in the lean clay at the wet of optimum moisture content. The maximum density values for the dry of optimum and optimum moisture contents were 87.1 and 91.3% of modified AASHO maximum, respectively, both at the 0- to 2-in. depth. As shown in plate 6, compactor C's density values are appreciably lower than those of the

rubber-tired roller except at the 0- to 2-in. depth in the wet of optimum moisture item, where they are about equal. The density increase for the rubber-tired roller between 4 and 16 coverages was 3.7 pcf for the dry of optimum moisture item, but only 1.4 and 1.0 pcf for the optimum and wet of optimum moisture items, respectively. Compactor C showed density increases between 4 and 16 coverages of 9.0 pcf in the dry of optimum item, 10.0 pcf in the optimum item, and 7.7 pcf in the wet of optimum item.

PART IV: SUMMARY OF RESULTS, AND CONCLUSIONS

Summary of Results

18. The overall compaction ability (with the materials and moisture contents used in these tests) of the compactors used in this investigation is tabulated below. The compactors are rated numerically in order of effectiveness (1 is best, 2 second best, etc.).

	Numerical Rating of Compactors A, B, C, and D											
	Dry of Optimum Moisture				Optimum Moisture				Wet of Optimum Moisture			
Material	A	B	C	D	A	B	C	D	A	B	C	D
Sand	3	4	2	1	4	3	2	1	4	3	1	2
Limestone	1	4	3	2	1	3	4	2	1	3	4	2
Lean clay	2	4	3	1	2	4	3	1	2	4	3	1

19. The information obtained from this investigation warrants the following observations:

- a. Compactor A, the heavy, low-frequency compactor, produced compaction similar to that of the 50-ton rubber-tired roller. Compactor A gave good compaction in limestone and lean clay, but not in sand.
- b. Compactor B, the lightweight, high-frequency compactor, showed good performance in the sand only, and this was at optimum and wet of optimum moisture and for a depth of 0 to 12 in. For most other materials and conditions tested, compactor B gave the poorest compaction.
- c. Compactor C, which was of intermediate weight and low frequency, produced the best compaction of any vibratory roller in the sand. It produced over 100% of modified AASHO maximum density at the 0- to 12-in. depth at wet of optimum moisture. Below the 0- to 12-in. depth, density fell off rapidly; therefore, this compactor would not be effective for lifts thicker than approximately 9 in. Compactor C was much less effective for compaction of limestone and lean clay than was compactor A or the rubber-tired roller.
- d. In the lean clay, about 4 coverages of the 50-ton rubber-tired roller were equivalent to 16 coverages of compactor A (the most effective vibratory roller in the lean clay).

e. The vibratory compactors gave their best compaction at wet of optimum moisture in the sand and at optimum moisture in the limestone and lean clay.

20. No analysis was made of the effect of frequency or centrifugal force of the vibratory compactors because sufficient information was not available to determine the force actually applied to the soil.

Conclusions

21. There is evidence that in sand being compacted with vibratory rollers the density will be a cyclic function of coverages. Plate 7 shows higher densities for 4 and 16 coverages than for 8 coverages. The effect of frequency is most apparent in sand. The lowest frequency middleweight compactor (C) did the best overall job of compacting the sand. For the limestone and lean clay it appears that the deadweight of the roller was the most important factor. Densities in these materials generally increased in direct proportion to increases in the deadweight of the vibratory rollers.

22. The results of the tests show that vibratory rollers, in spite of the claims of manufacturers, will not produce densities to any significantly greater depth than will rubber-tired rollers (exception: compactor A in limestone).

23. For comparable lift thickness of compaction, it may be possible to substitute much lighter vibratory rollers for heavy rubber-tired rollers; however, there is a limit to the amount of weight reduction that can be achieved through use of vibratory rollers.

Table 1

Summary of Density and Moisture Content Data, Sand Test Section - 16 Coverages

Test No.	Compactor A Moisture Content % Dry Wt	Compactor A Dry Density pcf	Compactor A % Modified AASHO Max	Compactor B Moisture Content % Dry Wt	Compactor B Dry Density pcf	Compactor B % Modified AASHO Max	Compactor C Moisture Content % Dry Wt	Compactor C Dry Density pcf	Compactor C % Modified AASHO Max	Compactor D Moisture Content % Dry Wt	Compactor D Dry Density pcf	Compactor D % Modified AASHO Max
						Dry of Optimum Moisture (7.0%)						
[illegible]	[illegible]	[illegible]	[illegible]	4.2	102.7	89.7	5.4	107.0	93.5	5.9	100.3	87.6
[illegible]	[illegible]	[illegible]	[illegible]	4.5	105.5	92.1	6.1	109.1	95.3	6.2	110.1	96.2
[illegible]	[illegible]	[illegible]	91.5	7.6	100.6	87.9	7.1	105.8	[illegible]	6.5	108.5	94.8
[illegible]	[illegible]	[illegible]	[illegible]	8.0	98.5	86.0	8.0	102.6	89.6	7.0	105.9	92.5
[illegible]	[illegible]	[illegible]	87.3	9.5	96.9	84.5	8.4	99.5	[illegible]	6.9	102.3	89.3
[illegible]	[illegible]	[illegible]	[illegible]	9.2	95.8	83.7	7.3	99.1	[illegible]	14.7	100.1	87.4
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--	--	--	--
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--	--	--	--
[illegible]	--	--	--	[illegible]	95.1	85.7	17.4	98.4	[illegible]	13.2	99.6	87.0
						Optimum Moisture (11.0-12.0%)						
[illegible]	[illegible]	[illegible]	[illegible]	5.5	[illegible]	91.2	[illegible]	[illegible]	[illegible]	[illegible]	105.4	92.1
[illegible]	[illegible]	[illegible]	[illegible]	7.7	[illegible]	[illegible]	[illegible]	111.3	[illegible]	[illegible]	[illegible]	97.9
[illegible]	[illegible]	[illegible]	[illegible]	7.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	113.5	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.5	86.5	7.7	107.3	93.7	[illegible]	114.6	100.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	95.1	85.7	[illegible]	[illegible]	[illegible]	[illegible]	111.5	97.4
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--	--	--	--
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--	--	--	--
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--	--	--	--
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	[illegible]	--	--	--
[illegible]	--	--	--	[illegible]	97.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	97.3
[illegible]	--	--	--	[illegible]	[illegible]	[illegible]	17.	[illegible]	[illegible]	13.	111.	97.1
						Wet of Optimum Moisture ([illegible])						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	104.7	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	7.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.3	114.3	99.9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	107.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	108.1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	--	--	--	17.1	[illegible]	[illegible]	--	--	--	--	--	--
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--	--	--	--
[illegible]	--	--	--	[illegible]	[illegible]	[illegible]	--	--	--	--	--	--
[illegible]	--	--	--	--	--	--	[illegible]	[illegible]	[illegible]	[illegible]	105.6	[illegible]

Table 2

Summary of Density and Moisture Content Data, Limestone Test Section - 16 Coverages

	Compactor A			Compactor B			Compactor C			Compactor D		
Depth in.	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max
						Dry of Optimum Moisture (1.0%)						
0-6	1.1	141.3	92.5	1.0	138.5	91.6	1.1	142.0	92.7	1.4	141.2	93.3
0-6	0.9	138.4	--	0.8	--	--	1.4	138.2	--	1.0	140.7	--
6-12	0.9	139.9	92.3	1.3	135.3	89.8	1.4	132.5	89.8	1.4	136.5	91.0
6-12	1.2	139.2	--	1.3	136.3	--	1.4	138.9	--	1.2	138.6	--
						Optimum Moisture (5.0%)						
0-6	1.9	149.1	98.1	1.4	143.8	94.7	2.6	143.9	95.6	2.4	149.4	98.7
0-6	2.1	147.4	--	1.5	142.5	--	2.5	145.0	--	2.5	149.0	--
6-12	2.1	140.9	95.8	1.5	140.7	92.5	1.9	136.6	88.8	2.4	141.0	94.6
6-12	1.9	148.7	--	1.9	138.9	--	2.4	132.0	--	2.6	144.8	--
						Wet of Optimum Moisture (7.0%)						
0-6	3.2	148.7	97.8	1.8	146.5	96.1	2.7	142.0	94.8	3.3	147.8	96.3
0-6	2.8	146.9	--	2.1	143.9	--	2.7	144.7	--	3.2	143.3	--
6-12	2.9	148.2	97.9	2.0	139.3	92.9	2.4	131.7	87.9	3.5	146.6	95.9
6-12	2.9	147.8	--	2.2	141.5	--	2.6	134.1	--	3.6	143.3	--

Table 3

Summary of Density and Moisture Content Data, Lean Clay Test Section - 16 Coverages

	Compactor A			Compactor B			Compactor C			Compactor D		
Depth In.	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max	Moisture Content % Dry Wt	Dry Density pcf	Avg % Modified AASHO Max
						Dry of Optimum Moisture (13.0%)						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	101.2	86.3	13.2	101.6	87.1	11.5	105.0	91.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80.0	13.2	96.6	[illegible]	13.7	100.9	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	89.1	77.1	12.9	91.9	78.1	13.0	99.0	84.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	87.7	75.0	12.6	90.7	77.7	12.0	97.2	93.0
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	--	--	74.4	11.1	95.4	81.8
[illegible]	--	--	--	--	--	--	--	--	--	12.2	95.8	[illegible]
[illegible]	[illegible]	[illegible]	--	[illegible]	101.0	--	13.8	102.5	--	12.8	100.4	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	13.7	97.7	--	[illegible]	105.0	--
[illegible]	[illegible]	[illegible]	--	[illegible]	91.7	--	13.1	91.2	--	13.0	99.4	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	13.4	91.3	--	11.8	97.4	--
[illegible]	[illegible]	[illegible]	--	--	--	--	14.2	87.2	--	11.6	96.2	--
[illegible]	--	--	--	--	--	--	--	--	--	12.0	96.3	--
						Optimum Moisture (14.[illegible]%)						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	91.3	16.7	[illegible]	93.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.3	[illegible]	[illegible]	[illegible]	107.6	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.4	97.8	83.8	18.4	[illegible]	91.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80.1	17.7	103.3	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	--	--	--	17.0	91.3	78.1	17.4	100.2	86.8
[illegible]	--	--	--	--	--	--	--	--	--	16.1	104.2	88.9
[illegible]	[illegible]	[illegible]	--	[illegible]	107.3	--	13.7	[illegible]	--	16.8	110.7	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	103.6	--	18.0	108.4	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	[illegible]	--	16.9	106.5	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	[illegible]	--	17.0	103.2	--
[illegible]	[illegible]	[illegible]	--	--	--	--	[illegible]	91.7	--	[illegible]	102.2	--
[illegible]	--	--	--	--	--	--	--	--	--	--	--	--
						Wet of Optimum Moisture ([illegible]%)						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.3	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	--	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.3	105.3	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.0	97.5	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.1	93.7	[illegible]	20.0	[illegible]	[illegible]
[illegible]	--	--	--	--	--	--	--	--	--	[illegible]	104.6	[illegible]
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	107.2	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	106.0	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	106.1	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	106.9	--
[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	--	[illegible]	91.5	--	[illegible]	107.6	--
[illegible]	--	--	--	--	--	--	--	--	--	[illegible]	107.1	--

Table 4

Summary of Density, Moisture, and Coverage Data at Surface

[illegible]	Compactor A						Compactor B						Compactor C						Compactor D						Remarks
	Dry of Optimum		Optimum		Wet of Optimum		Dry of Optimum		Optimum		Wet of Optimum		Dry of Optimum		Optimum		Wet of Optimum		Dry of Optimum		Optimum		Wet of Optimum		
	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	
												Sand Test Section													
[illegible]	7.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.9	106.3	4.8	102.6	9.3	101.2	12.0	105.8	6.6	999.2	*	*	*	*	Direct samples
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.1	[illegible]	6.8	94.3	12.6	103.9	6.3	100.1	8.1	95.0	11.0	103.4	5.0	102.4	7.8	98.9	9.1	110.2	Direct samples
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	102.7	5.5	104.4	7.3	113.0	5.4	107.0	6.1	104.9	8.8	116.3	5.9	100.3	6.9	105.4	9.9	104.7	Direct samples
												Limestone Test Section													
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.6	135.1	7.8	137.8	2.6	[illegible]	6.6	135.7	8.1	136.9	2.6	[illegible]	7.5	136.0	9.2	139.6	Road logger
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	141.0	3.1	[illegible]	5.1	135.5	7.7	136.4	2.7	138.1	6.8	134.5	7.8	137.8	2.6	134.1	7.2	135.4	8.8	141.3	Road logger
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.6	[illegible]	8.0	[illegible]	3.0	140.2	6.5	142.1	8.4	140.2	2.6	136.1	7.4	137.0	8.6	143.7	Road logger
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	138.5	1.5	143.2	[illegible]	145.3	1.3	140.2	2.6	144.5	2.7	143.3	1.2	141.1	2.5	149.2	3.3	145.6	Direct samples
												Lean Clay Test Section													
[illegible]	[illegible]	[illegible]	15.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.3	98.6	20.7	103.4	13.8	93.1	17.6	97.0	21.9	99.8	14.7	103.5	18.0	108.4	20.5	106.0	Direct samples
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	101.1	17.0	107.4	20.5	106.4	13.5	102.1	17.8	107.0	19.3	107.5	12.2	[illegible]	16.8	109.8	19.8	107.0	Direct samples

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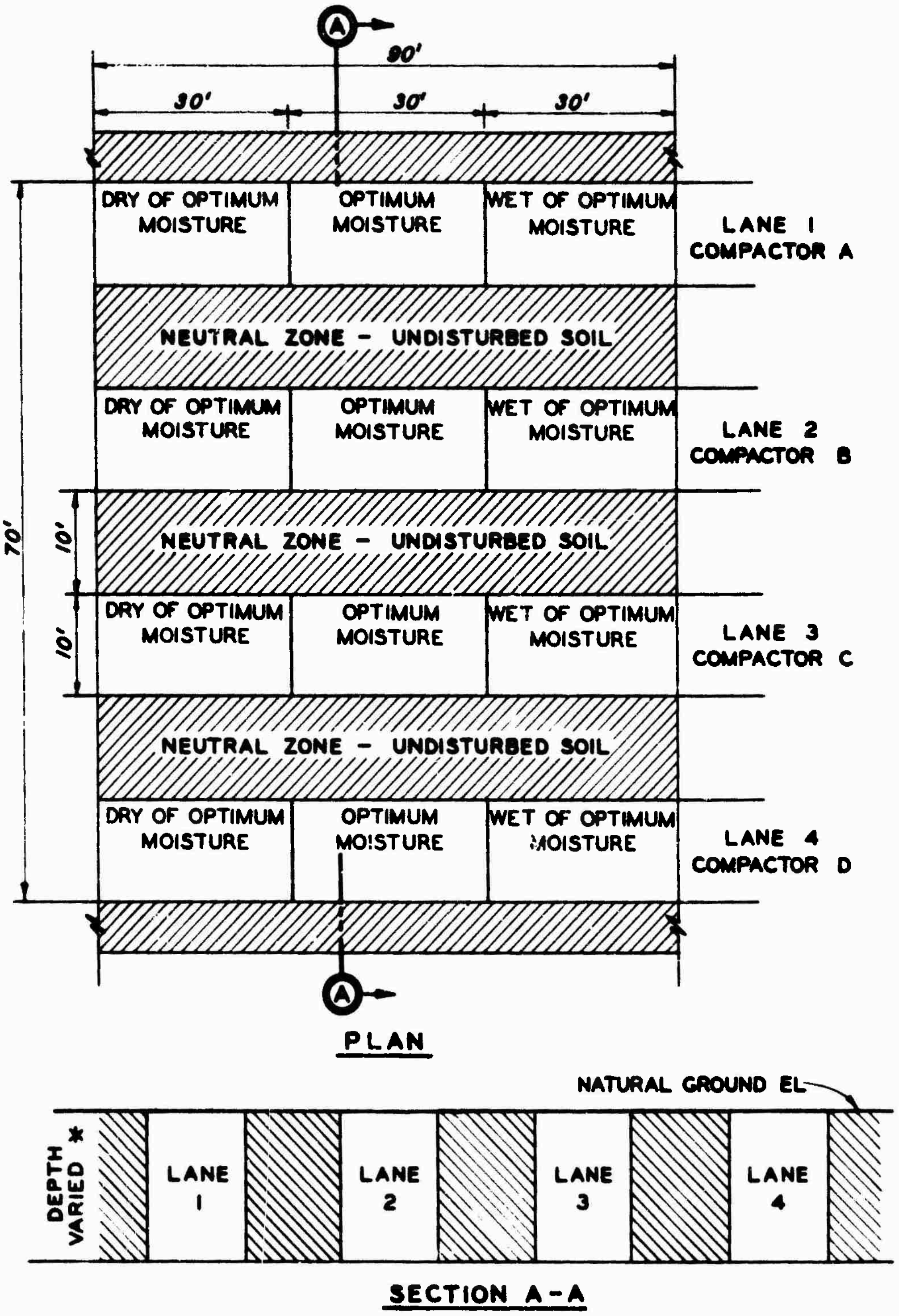
* [illegible] necessary to provide additional tow.

Table 5

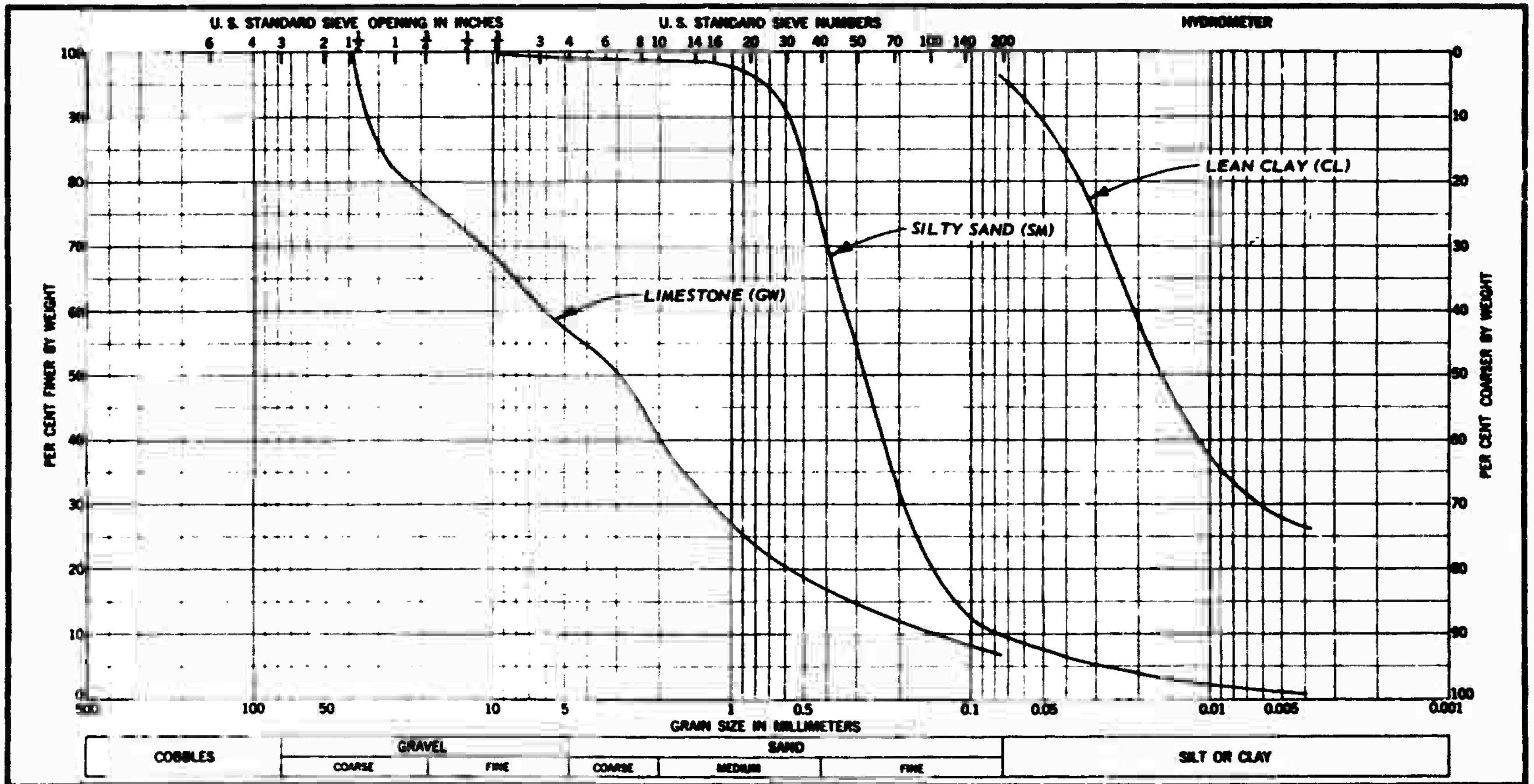
Ground Deflection Data

Cover-ages	Sand Test Section						Limestone Test Section						Lean Clay Test Section					
	Dry of Optimum Moisture		Optimum Moisture		Wet of Optimum Moisture		Dry of Optimum Moisture		Optimum Moisture		Wet of Optimum Moisture		Dry of Optimum Moisture		Optimum Moisture		Wet of Optimum Moisture	
	Frequency cps	Displacement in.	Frequency cps	Displacement in.	Frequency cps	Displacement in.	Frequency cps	Displacement in.	Frequency cps	Displacement in.	Frequency cps	Displacement in.	Frequency cps	Displacement in.	Frequency cps	Displacement in.	Frequency cps	Displacement in.
							Compactor A, 1-ft Depth											
1L	--	--	--	--	--	--	17.75	0.0132	17.40	0.0114	17.20	0.0525	20.0	0.018	20.0	0.013	--	--
1R	--	--	--	--	--	--	17.40	0.0219	17.40	0.0322	17.75	0.0346	15.1	0.010	15.0	0.0068	--	--
2L	17.00	0.013	18.00	0.010	--	--	17.20	0.0241	17.00	0.0102	17.00	0.0646	15.4	0.013	15.1	0.017	--	--
2R	16.00	0.008	17.00	0.007	--	--	17.40	0.0326	17.75	0.0363	17.75	0.0444	15.2	0.015	15.1	0.011	--	--
3L	--	--	--	--	--	--	17.75	0.0371	17.40	0.0400	17.10	0.0646	--	--	--	--	--	--
3R	--	--	--	--	--	--	17.50	0.0421	17.60	0.0533	17.20	0.0660	--	--	--	--	--	--
4L	18.00	0.013	18.00	0.010	--	--	17.00	0.0340	17.00	0.0375	17.05	0.0680	18.0	0.039	18.0	0.029	18.0	0.004
4R	18.00	0.010	18.00	0.009	18.00	0.008	17.00	0.0566	17.00	0.0644	17.00	0.0739	17.0	0.047	17.0	0.028	17.0	0.012
8L	17.00	0.017	17.00	0.012	17.00	0.011	18.00	0.0622	18.00	0.0684	18.50	0.0736	16.4	0.026	16.0	0.044	--	--
8R	17.00	0.013	17.00	0.012	17.00	0.011	18.00	0.0685	18.00	0.0766	18.00	0.0756	16.0	0.015	16.0	0.045	--	--
16L	17.00	0.013	17.00	0.009	17.00	0.009	19.60	0.0452	19.75	0.0631	19.75	0.0819	16.0	0.014	16.0	0.027	--	--
16R	17.00	0.011	17.00	0.010	17.00	0.008	20.00	0.0521	19.50	0.0859	19.50	0.0744	16.0	0.019	16.0	0.031	--	--
							Compactor B											
	Optimum Moisture Content																	
	1-ft Depth		2-ft Depth		4-ft Depth		1-ft Depth											
1L	59.0	0.008	59.0	0.005	59.0	0.001	58.5	0.0117	60.0	0.0184	60.0	0.0041	60.0	0.008	60.2	0.005	60.6	0.004
1R	--	--	--	--	--	--	60.0	0.0148	60.5	0.0112	60.5	0.0132	--	--	--	--	--	--
2L	--	--	--	--	--	--	59.0	0.0067	60.0	0.0075	60.0	0.0139	60.0	0.004	60.0	0.003	60.2	0.002
2R	--	--	--	--	--	--	59.5	0.0176	59.5	0.0086	60.0	0.0030	--	--	--	--	--	--
4L	58.0	0.009	58.0	0.006	58.0	0.003	59.5	0.0177	60.5	0.0144	--	--	60.0	0.006	60.0	0.008	60.0	0.005
4R	--	--	--	--	--	--	59.0	0.0028	59.0	0.0070	59.0	0.0033	--	--	--	--	--	--
8L	59.0	0.009	59.0	0.006	59.0	0.002	60.0	0.0197	60.0	0.0135	60.0	0.0144	60.0	0.012	60.0	0.011	60.0	0.009
8R	--	--	--	--	--	--	60.0	0.0143	60.0	0.0037	60.0	0.0106	--	--	--	--	--	--
16	59.0	0.013	59.0	0.007	59.0	0.004	--	--	--	--	--	--	60.0	0.014	60.0	0.012	60.0	0.010
							Compactor C											
1	14.5	0.011	14.5	0.051	14.5	0.055	10.5	0.0240	11.0	0.0254	11.0	0.0154	11.5	0.016	12.4	0.009	12.2	0.008
2	14.5	0.01	14.5	0.023	14.5	0.041	11.0	0.0329	11.0	0.0297	11.0	0.0258	12.2	0.038	12.5	0.018	11.5	0.020
4	14.0	0.013	14.0	0.028	14.0	0.056	11.2	0.0306	11.5	0.0400	10.7	0.0237	12.5	0.040	12.0	0.023	12.2	0.017
8	15.0	0.015	15.0	0.027	15.0	0.048	11.0	0.0253	11.0	0.0316	11.0	0.0455	14.0	0.069	13.5	0.031	13.0	0.023
16	13.0	0.015	13.0	0.046	13.0	0.050	11.0	0.0481	11.0	0.0600	11.0	0.0718	12.4	0.085	12.4	0.048	12.3	0.024



* DEPTH WAS 1 FOOT FOR LIMESTONE AND LEAN CLAY TEST SECTIONS, AND 4 FEET FOR FINE SAND TEST SECTION.

TYPICAL LAYOUT OF TEST SECTION



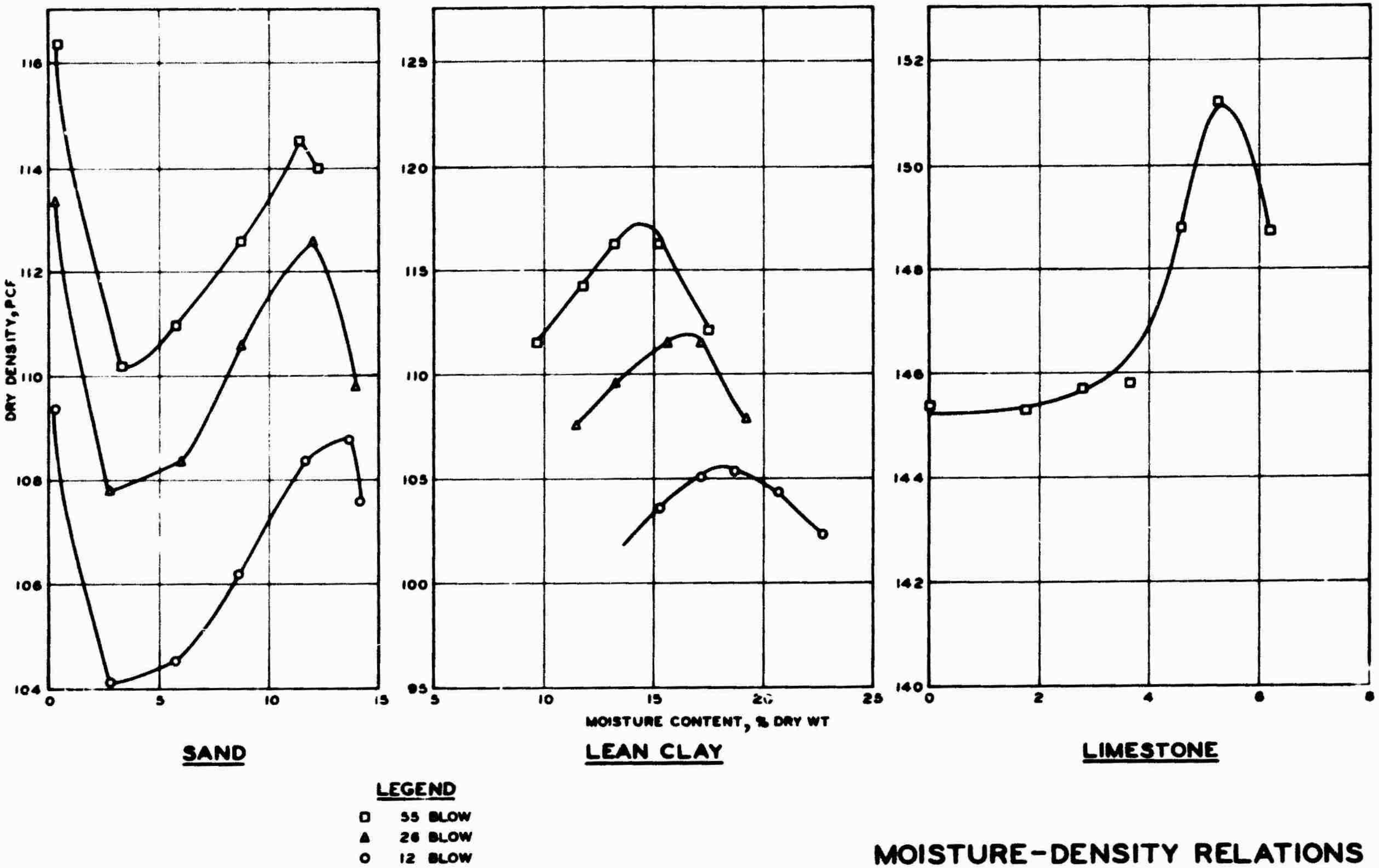
Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	1 FT	CRUSHED LIMESTONE (GW)				
	4 FT	SILTY SAND (SM)				
	1 FT	LEAN CLAY (CL)		47	24	23

GRADATION CURVES

GRADATION OF TEST SOILS

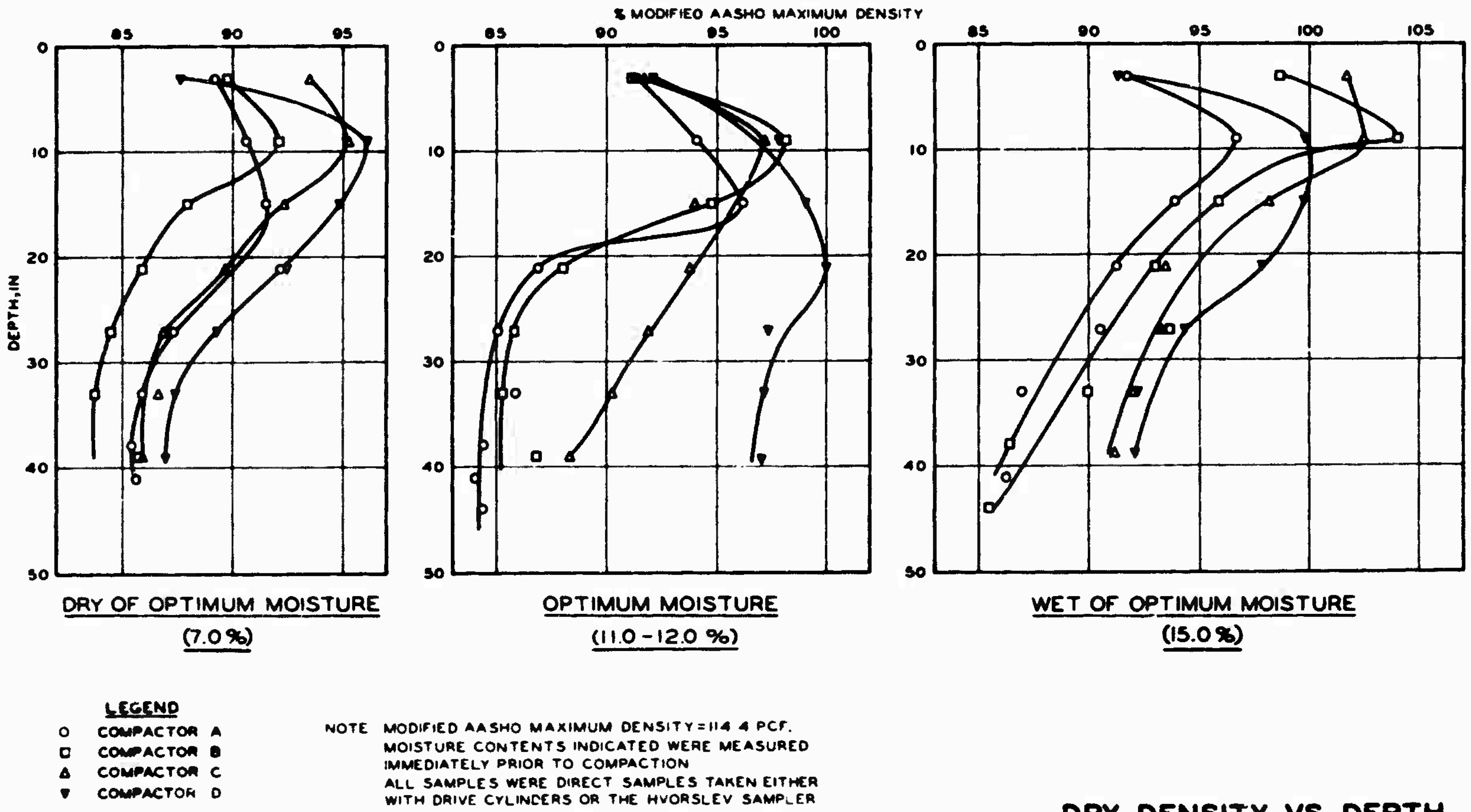
WES FORM NO 1241
SEPT 1962

PLATE 2



MOISTURE-DENSITY RELATIONS

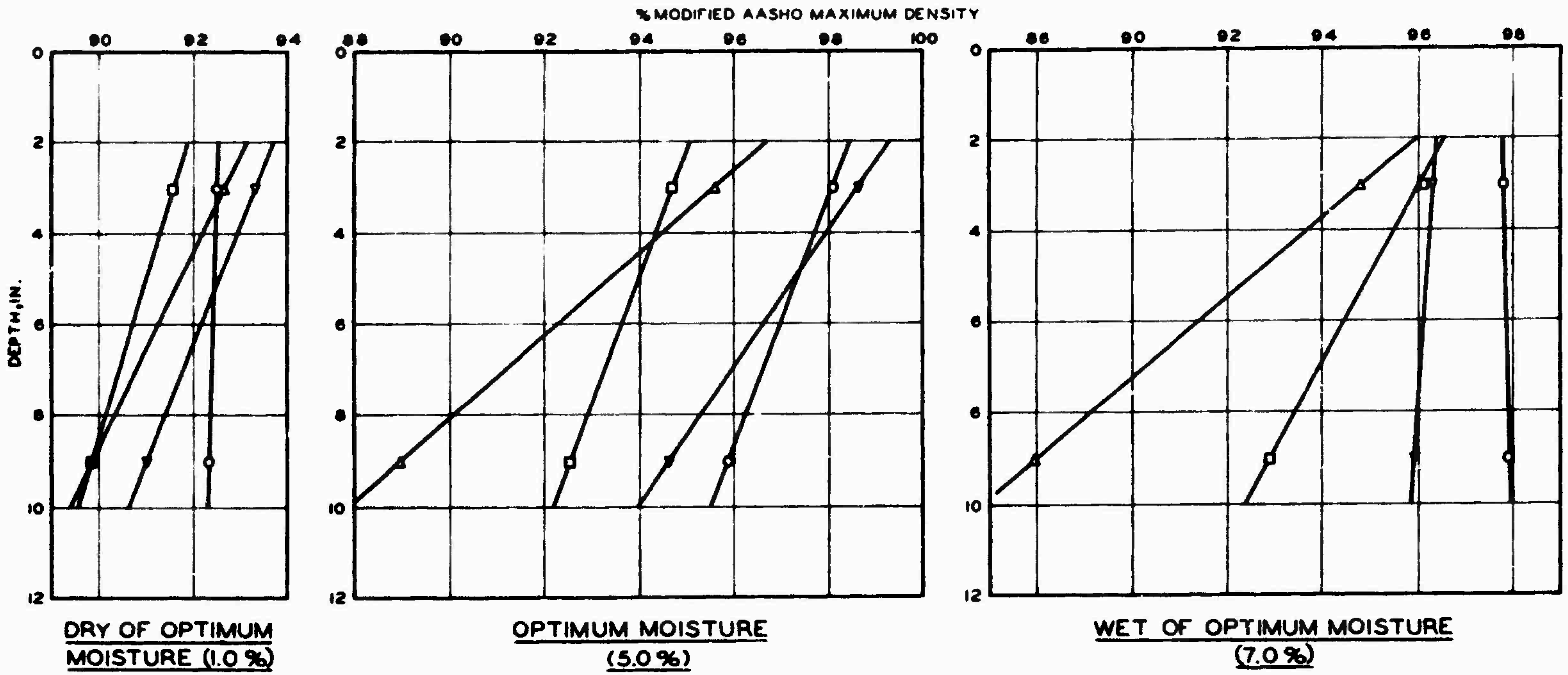
PLATE 3



NOTE MODIFIED AASHO MAXIMUM DENSITY=114.4 PCF.
MOISTURE CONTENTS INDICATED WERE MEASURED IMMEDIATELY PRIOR TO COMPACTION
ALL SAMPLES WERE DIRECT SAMPLES TAKEN EITHER WITH DRIVE CYLINDERS OR THE HVORSLEV SAMPLER

DRY DENSITY VS DEPTH
SAND
16 COVERAGES

PLATE 4



DRY OF OPTIMUM MOISTURE (1.0 %)

OPTIMUM MOISTURE (5.0 %)

WET OF OPTIMUM MOISTURE (7.0 %)

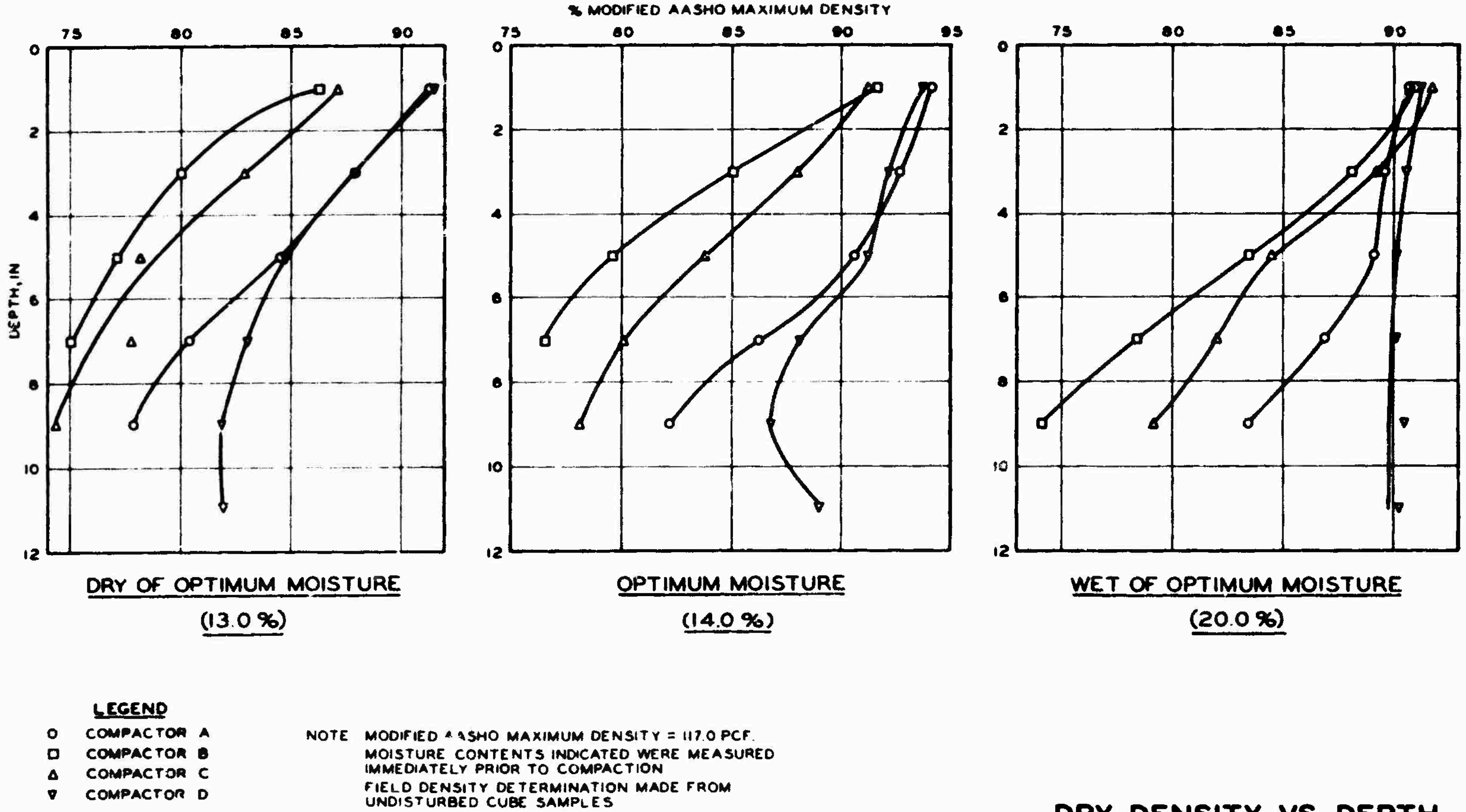
LEGEND

- o COMPACTOR A
- ◻ COMPACTOR B
- △ COMPACTOR C
- ▼ COMPACTOR D

NOTE MODIFIED AASHO MAXIMUM DENSITY = 151.2 PCF.
MOISTURE CONTENTS INDICATED WERE MEASURED IMMEDIATELY PRIOR TO COMPACTION.
UNIT DRY WEIGHT OF SOIL DETERMINED BY WES SAND DISPLACEMENT METHOD.
EACH POINT PLOTTED IS AVERAGE OF TWO OR MORE TESTS.

DRY DENSITY VS DEPTH
CRUSHED LIMESTONE
16 COVERAGES

PLATE 5



DRY OF OPTIMUM MOISTURE
(13.0 %)

OPTIMUM MOISTURE
(14.0 %)

WET OF OPTIMUM MOISTURE
(20.0 %)

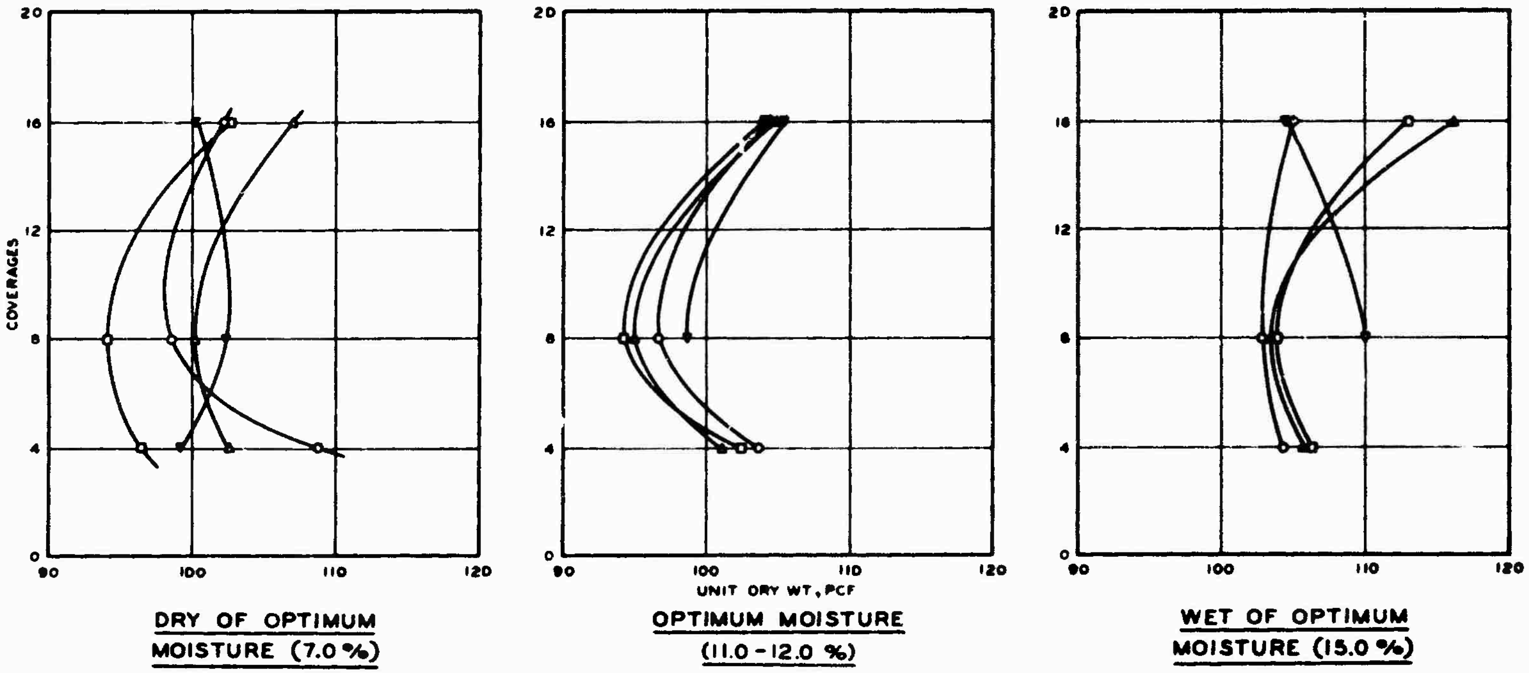
LEGEND

○	COMPACTOR A
□	COMPACTOR B
△	COMPACTOR C
▽	COMPACTOR D

NOTE MODIFIED AASHO MAXIMUM DENSITY = 117.0 PCF.
MOISTURE CONTENTS INDICATED WERE MEASURED IMMEDIATELY PRIOR TO COMPACTION
FIELD DENSITY DETERMINATION MADE FROM UNDISTURBED CUBE SAMPLES

DRY DENSITY VS DEPTH
LEAN CLAY
16 COVERAGES

PLATE 6



NOTE: ALL SAMPLES WERE DIRECT SAMPLES TAKEN EITHER WITH DRIVE CYLINDERS OR WITH HVORSLEV SAMPLER.

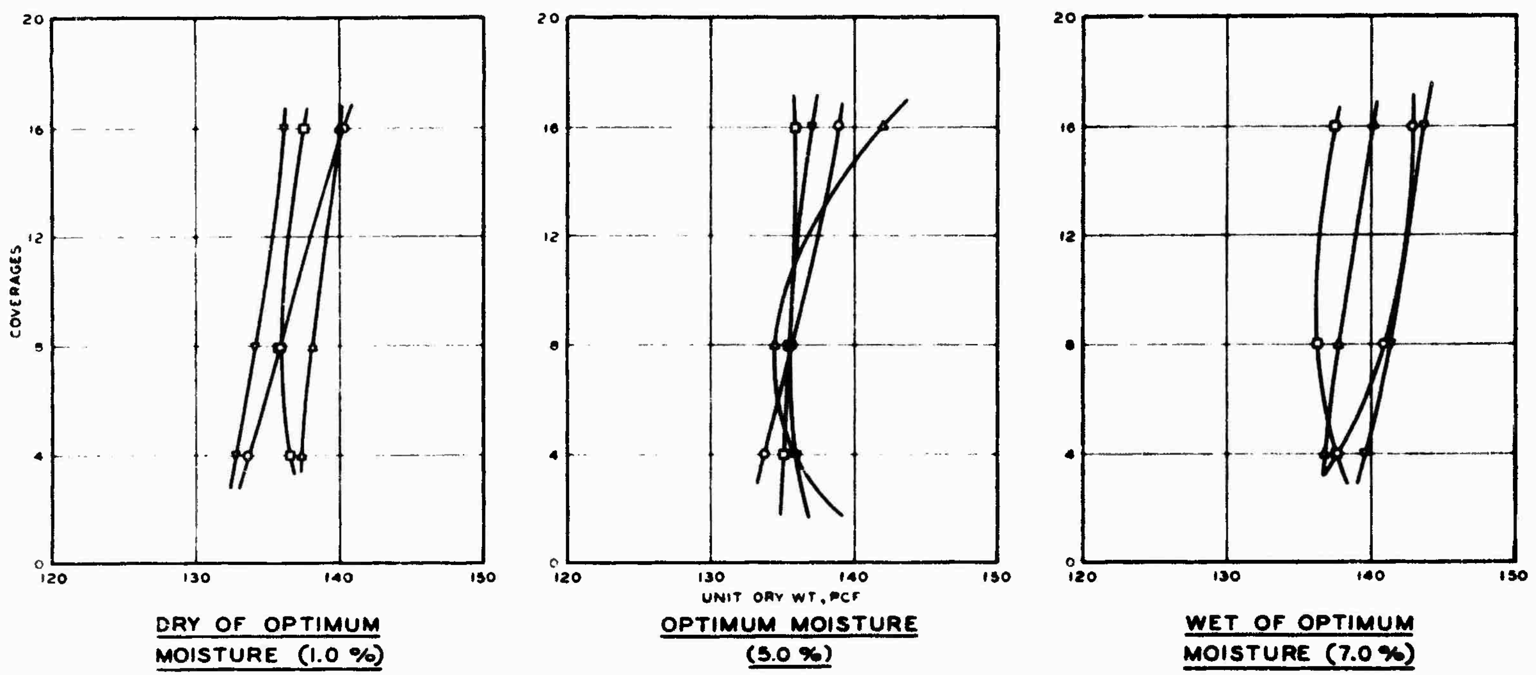
ALL DENSITIES SHOWN WERE SURFACE DENSITIES (0- TO 4-IN. MAXIMUM DEPTH).

MODIFIED AASHO MAXIMUM DENSITY = 114.4 PCF.

MOISTURE CONTENTS INDICATED WERE MEASURED IMMEDIATELY PRIOR TO COMPACTION.

COVERAGES VS DENSITY
SAND

PLATE 8



DRY OF OPTIMUM MOISTURE (1.0 %)

OPTIMUM MOISTURE (5.0 %)

WET OF OPTIMUM MOISTURE (7.0 %)

LEGEND

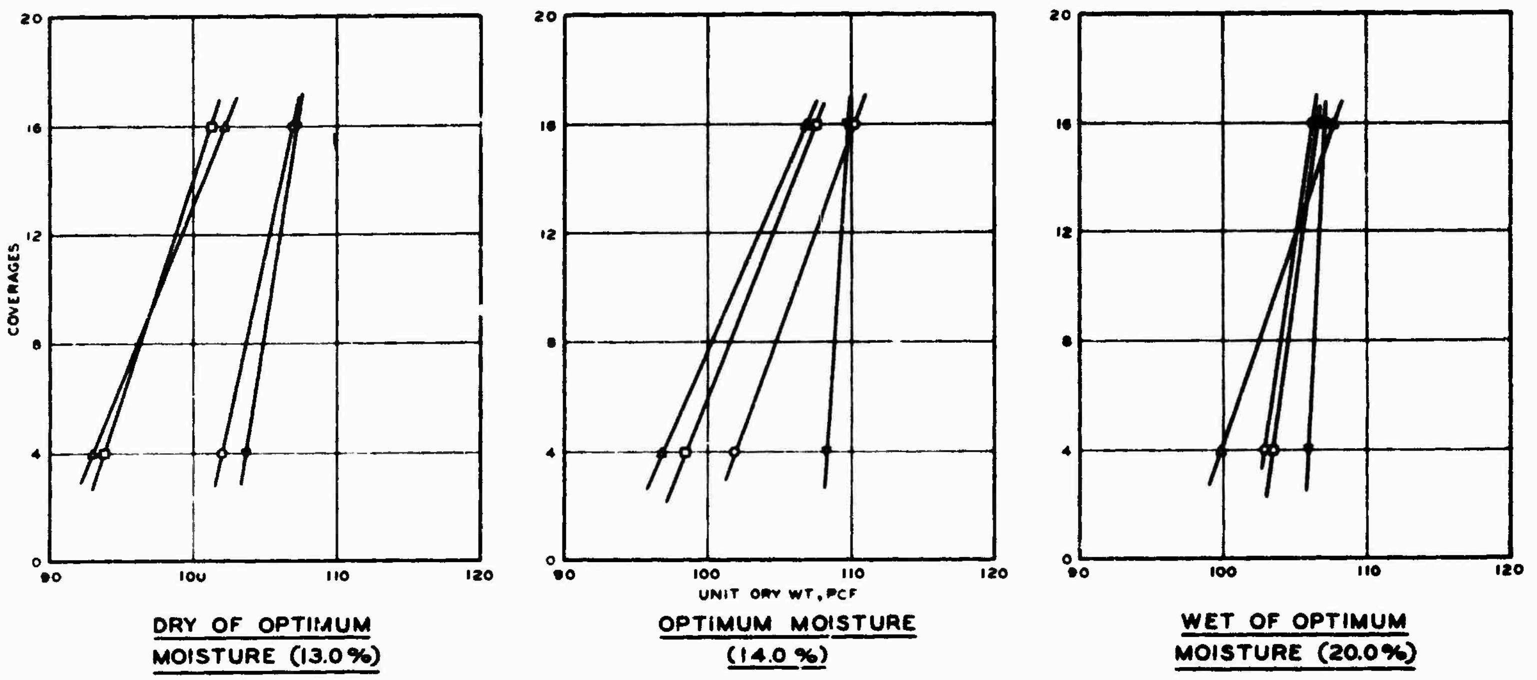
- ○ COMPACTOR A
- □ COMPACTOR B
- △ COMPACTOR C
- ▽ COMPACTOR D

NOTE: ALL READINGS ARE FROM THE ROAD LOGGER METHOD OF DENSITY DETERMINATION BY NUCLEONIC RADIATION RETURN

MODIFIED AASHO MAXIMUM DENSITY = 151.2 PCF.

MOISTURE CONTENTS INDICATED WERE MEASURED IMMEDIATELY PRIOR TO COMPACTION.

COVERAGES VS DENSITY
LIMESTONE



NOTE: SAMPLES AT 4 COVERAGES AND AT 16 COVERAGES WERE UNDISTURBED CUBE SAMPLES.

MODIFIED AASHO MAXIMUM DENSITY = 117.0 PCF.

MOISTURE CONTENTS INDICATED WERE MEASURED IMMEDIATELY PRIOR TO COMPACTION.

COVERAGES VS DENSITY
LEAN CLAY

PLATE 9

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13. ABSTRACT

This study was conducted for the purpose of determining the ability of vibratory rollers to compact soils. For comparative purposes, a 50-ton rubber-tired roller was used which is a required compaction device in present Corps of Engineers Guide Specifications. Three vibratory rollers were selected for study based on their operating frequency which encompassed the range over which present vibratory rollers operate. Results of this study show that light vibratory rollers can obtain satisfactory densities if lift thicknesses are restricted. To evaluate the vibratory rollers, each was used to compact three soil types (a lean clay, a crushed limestone, and a clean sand). Results indicate that a heavy, low-frequency vibratory roller will compact to greater depths than a light, high-frequency roller; however, the light, high-frequency roller will compact soil satisfactorily for a few inches below the surface. Soil types have a very definite influence on results obtained with vibratory rollers. The vibratory rollers generally perform better in granular soils; however, the heavy, low-frequency type rollers do a satisfactory job in clay soils.

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